UNIVERSITY
OF WOLLONGONG
AUSTRALIA

University of Wollongong
Research Online

Faculty of Engineering and Information Sciences - Papers: Part A

Faculty of Engineering and Information Sciences

2017

Experimental and Modelling Approaches to the Determination of Fatigue Crack Growth from a Structural Steel T-Butt Weld Toe

V. Tanulia
University of New South Wales

B. G. Prusty
University of New South Wales

G. M. Pearce
University of New South Wales

Alan K. Hellier
University of Wollongong, ahellier@uow.edu.au

H. Li.
University of Wollongong

See next page for additional authors

Publication Details

V. Tanulia, B.G. Prusty, G.M. Pearce, A.K. Hellier, H. Li, M. Reid and A.M. Paradowska, Experimental and Modelling Approaches to the Determination of Fatigue Crack Growth from a Structural Steel T-Butt Weld Toe, Proceedings of the 9th Australasian Congress on Applied Mechanics (ACAM9), Sydney, Engineers Australia, 27-29 November 2017. Poster

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

Experimental and Modelling Approaches to the Determination of Fatigue Crack Growth from a Structural Steel T-Butt Weld Toe

Abstract

T-butt welded joints are found in many structural steel applications including buildings, bridges and offshore structures and are susceptible to fatigue crack initiation and propagation,which often leads ultimately to fast fracture failure. An example ofthis was the I-35W bridge in Minneapolis, which collapsed in 2007 resulting in 13 fatalities, as shown in Figure 1 [1]. The experimental work for this project was conducted using A350 grade black mild steel plate. An ultrasonic peening treatment was applied to one T-butt specimen to introduce compressive residual stress at the weld toe, in order to reduce the effective fatigue crack propagation rate. The results generated from 3-D FEA modelling plus a FORTRAN program (implementing parametric stress intensity factor and crack propagation equations) will be compared with experimental fatigue test results.

Disciplines

Engineering | Science and Technology Studies

Publication Details

V. Tanulia, B.G. Prusty, G.M. Pearce, A.K. Hellier, H. Li, M. Reid and A.M. Paradowska, Experimental and Modelling Approaches to the Determination of Fatigue Crack Growth from a Structural Steel T-Butt Weld Toe, Proceedings of the 9th Australasian Congress on Applied Mechanics (ACAM9), Sydney, Engineers Australia, 27-29 November 2017. Poster

Authors

V. Tanulia, B. G. Prusty, G. M. Pearce, Alan K. Hellier, H. Li., M. Reid, and A. M. Paradowska

This conference paper is available at Research Online: https://ro.uow.edu.au/eispapers/6778

Experimental and Modelling Approaches to the Determination of Fatigue Crack Growth from a Structural Steel T-Butt Weld Toe

Never Stand Still | Faculty of Engineering

V. Tanulia, B.G. Prusty and G.M. Pearce (UNSW), A.K. Hellier and H. Li (University of Wollongong), M. Reid and A.M. Paradowska (ANSTO)

PROJECT AIMS

- T-butt welded joints are found in many structural steel applications including buildings, bridges and offshore structures and are susceptible to fatigue crack initiation and propagation, which often leads ultimately to fast fracture failure.
- An example of this was the I-35W bridge in Minneapolis, which collapsed in 2007 resulting in 13 fatalities, as shown in Figure 1 [1].
- The experimental work for this project was conducted using A350 grade black mild steel plate.
- An ultrasonic peening treatment was applied to one T-butt specimen to introduce compressive residual stress at the weld toe, in order to reduce the effective fatigue crack propagation rate.
- The results generated from 3-D FEA modelling plus a FORTRAN program (implementing parametric stress intensity factor and crack propagation equations) will be compared with experimental fatigue test results.

Figure 1: I-35W bridge collapse in Minneapolis [1].

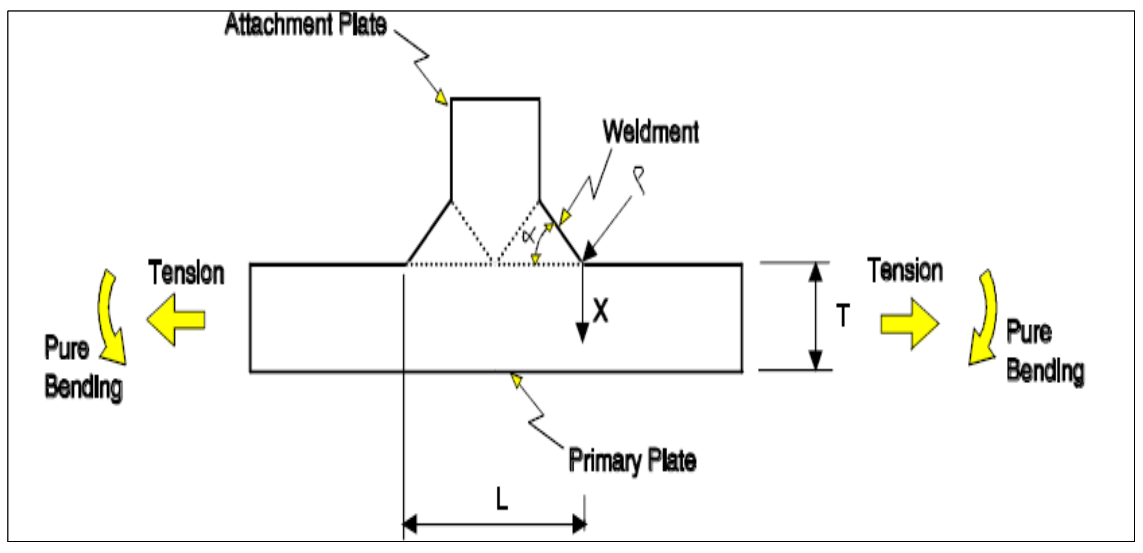

Figure 2: Schematic geometry of T-butt weld specimen [2].

Table 1: Geometric and material properties of T-butt weld.

Parameter	Value
Plate thickness (T)	10mm
Attachment width (L)	30mm
Weld angle (α)	45°
Weld toe radius (ρ)	0.1mm
Initial crack depth (a_i)	2mm
Initial crack width ($2c_i$)	40mm
a/c	0.1
Fatigue crack growth threshold (ΔK_{Ith})	3.2 MPa$\sqrt{m}$
Young's modulus (E)	213 GPa
Yield stress (σ_y)	350 MPa

Figure 3: T-butt weld specimen for experimental test.

APPROACHES

1. Finite Element Analysis (FEA)
Computational Approach:

- A three-dimensional fatigue life cycle model of a T-butt welded specimen under tension (membrane) loading was implemented using ANSYS (Workbench version 17.2).
- The boundary conditions were applied in accordance with the experimental testing, as illustrated in Figure 4a.
- The crack mesh structure was set to tetrahedron in order to achieve local refinement with a smooth change (Figure 4b).
- The number of stress cycles was calculated using the Paris Law propagation equation together with the FEA stress intensity factor (SIF) range for various crack lengths (from 2mm to 7mm).

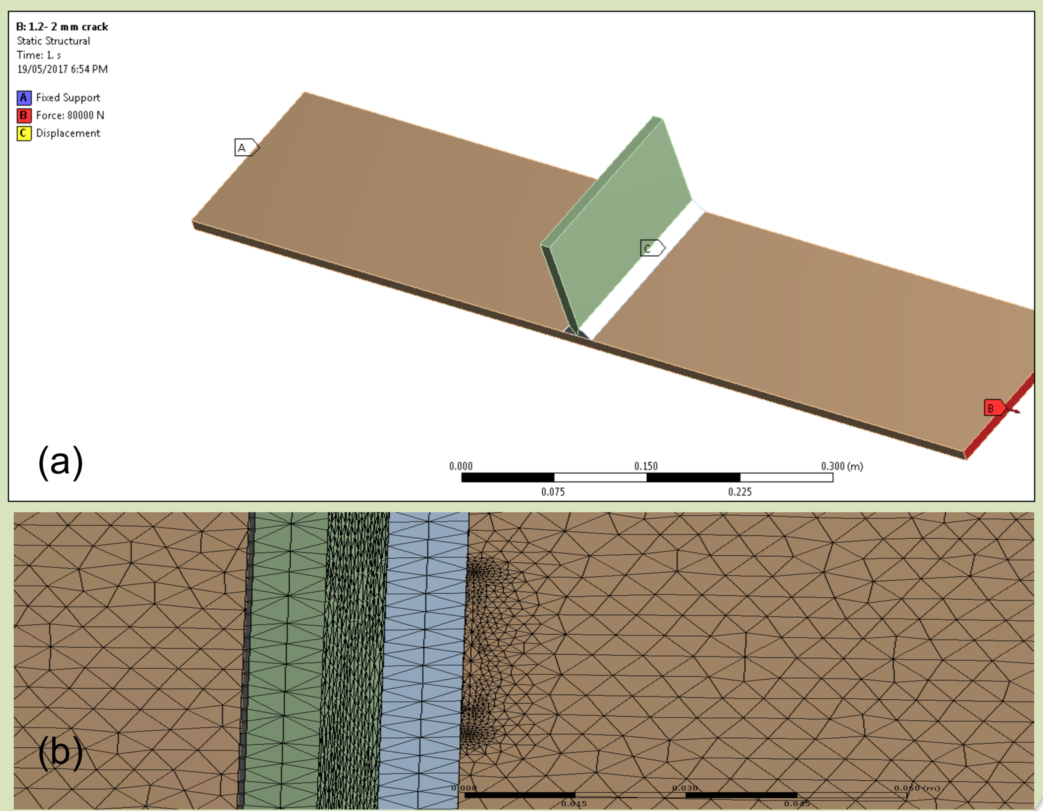

Figure 4: (a) Boundary condition placements; (b) Mesh refinement method.

2. FORTRAN Program
Analytical Approach:

- A fatigue crack propagation life program has been written in FORTRAN based on the tensile BDKH parametric equation along with the Paris Law propagation equation.
- The geometric input parameters used to predict the number of stress cycles are enumerated in Table 1.
- The FORTRAN program has been thoroughly tested for convergence. The best result was achieved with a number of 100,000 crack increments.
- The number of stress cycles taken was predicted using crack lengths from 2mm to 7mm with a 1mm increment.

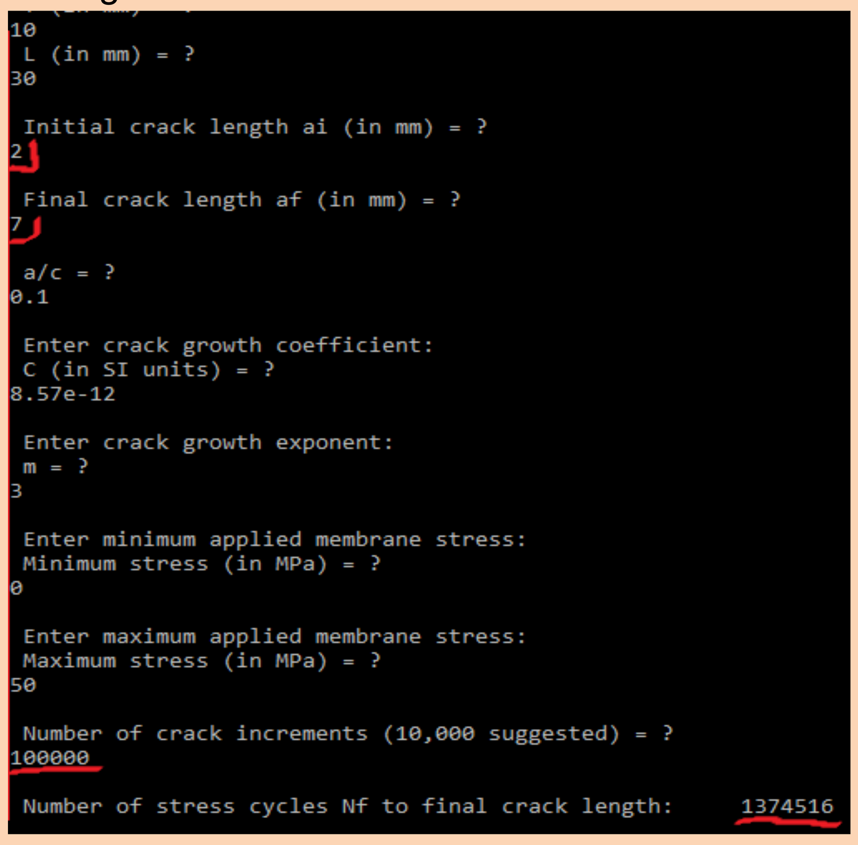

Figure 5: Number of stress cycles analysis using FORTRAN program with initial crack length 2mm and final crack length 7mm.

3. Experimental Test
Experimental Approach:

- A T-butt welded specimen was fabricated from A350 grade black mild structural steel material.
- A schematic diagram of the T-butt welded specimen is given in Figure 2.
- A semi-elliptical notch 2mm deep by 40mm wide was wire cut on one side of the specimen as shown in Figure 3.
- Fatigue testing was conducted using an INSTRON Digital 8804 servo-hydraulic testing machine.
- This experiment was conducted to determine whether the simulation model and BDKH parametric equation were able to provide accurate prediction of the number of stress cycles.

Figure 6: Experimental set-up for T-butt fatigue testing under tension (membrane) loading condition.

FATIGUE CRACK GROWTH PREDICTION EQUATIONS

1. Brennan-Dover-Karé-Hellier (BDKH) Parametric Equations

The BDKH parametric equations were developed to calculate SIF for the deepest point of a semi-elliptical crack at a T-butt weld toe.
The equation for tension (membrane) loading is:

$$Y_t = 1.03\left(\frac{a}{T}\right)^P e^{\left\{C_0+C_1\left(\frac{a}{T}\right)+C_2\left(\frac{a}{T}\right)^2\right\}+C_3+C_4}$$

where a is crack depth, T is base plate thickness and parameters C_i are constants [3].

2. Paris Law

Paris and Erdogan (1963) proposed a simple crack propagation equation by assuming fatigue crack propagation rate (da/dN) was dependent on SIF range (ΔK). Their crack propagation equation is as follows:

$$\frac{da}{dN} = C.(\Delta K)^n$$

where C is the fatigue crack growth constant, n is the fatigue crack growth exponent [4].

RESULTS

Table 2: SIF range results from FEA simulation and FORTRAN program. The number of 0-50 MPa stress cycles was calculated using the Paris Law with fatigue crack growth exponent equal to 3. The differences in predictions between the two methods are shown as a percentage.

Crack Length (mm)	SIF Range MPa $\sqrt{m}$			Number of stress cycles to final crack length		
	FEA Simulation	FORTRAN Program	Difference (%)	FEA Simulation	FORTRAN Program	Difference (%)
2	4.08	4.61	13.00	0	0	0
3	5.38	6.10	12.75	748,757	753,675	0.66
4	7.18	7.98	11.14	1,064,001	1,105,222	3.87
5	9.38	10.34	9.07	1,205,389	1,265,481	4.98
6	12.36	13.30	7.43	1,267,185	1,340,451	5.78
7	16.61	17.02	2.04	1,292,648	1,374,516	6.33

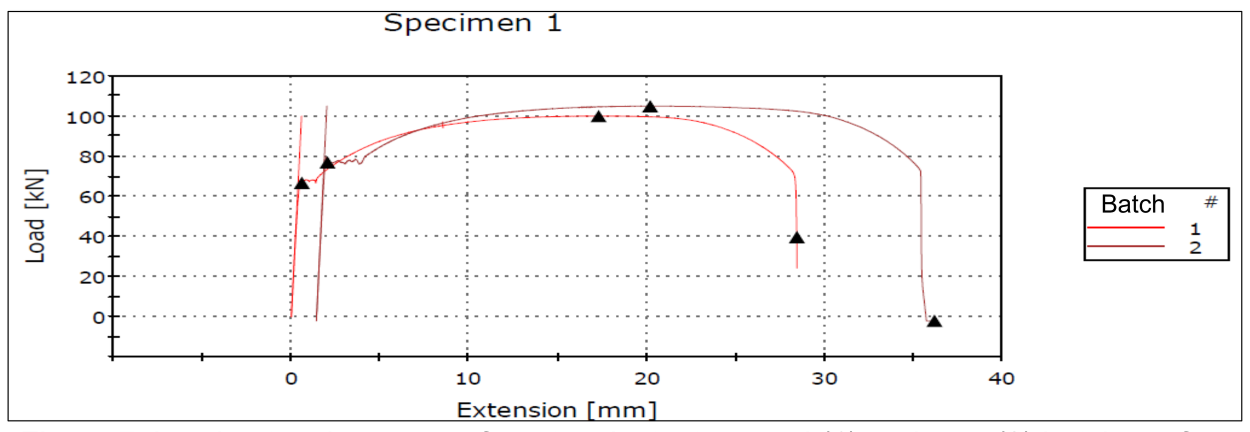

Figure 7: Load-extension curves from tensile tests on old (1) and new (2) batches of steel.

CONCLUSIONS

In this study the SIF was investigated using both FEA simulation and a FORTRAN program. Both models were in close agreement when predicting the SIF range and fatigue propagation life of a T-butt welded specimen with a semi-elliptical flaw. Material characterisation (tensile testing, Charpy testing) was performed in order to check that the material used in this experiment was consistent with the mill certificate and conformed to standards.

FUTURE WORK

- A full fatigue test on a notched T-butt under tension (membrane) loading is underway.
- Further material characterisation (notched tensile fatigue threshold testing) is currently being planned. The specimens have already been machined.

REFERENCES

[1] HAO, S. 2010. I-35W bridge collapse. *ASCE Journal of Bridge Engineering*, 15(5), pp. 608-614.
[2] HELLIER, A.K., BRENNAN, F.P. & CARR, D.G. 2014. Weld toe SCF and stress distribution parametric equations for tension (membrane) loading. In Proc. Fatigue 2014, 11th International Fatigue Congress, MCG, Melbourne, 2-7 March. *Advanced Materials Research, Trans Tech Publ.*, 891-892, pp. 1525-1530.
[3] BRENNAN, F.P., DOVER, W.D., KARÉ, R.F. & HELLIER, A.K. 1999. Parametric equations for T-butt weld toe stress intensity factors. *International Journal of Fatigue*, 21(10), pp. 1051-1062.
[4] PARIS, P. & ERDOGAN, F. 1963. A critical analysis of crack propagation laws. *Journal of Basic Engineering, Trans. ASME, Series D*, 85(4), pp. 528-534.